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NRL Memorandum Report 1383

ABYSSAL CORROSION AND ITS MITIGATION

PART II. RESULTS OF A PILOT TEST EXPOSURE

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CONTENTS

ABSTRACT

A second deep-sea corrosion experiment on behalf of the TRIDENT Office, Bureau of Ships has been terminated after 111 days exposure. This was conducted in 5700 feet of water in the Tongue of the Ocean, Bahama Islands. Results for structural metals and non-metallics are reported. Details of the design of the moor and retrieval procedures are given for possible benefits of others planning similar operations.

PROBLEM STATUS

This concludes one phase of the project. Other related surface experiments are in progress, an additional deep sea experiment (T-VIII) has been retrieved, a surface experiment (T-2) has been retrieved but has not been completely evaluated, still a further deep sea experiment (T-X) is in progress and another is being planned for initiation in early 1963.

AUTHORIZATION

NRL PROBLEM NUMBER: M04-02

BUREAU PROJECT NUMBER: SR 007-08-11, TASK 2829

DISTRIBUTION

Standard TRIDENT DIST list ..(as indicated)

INTRODUCTION

In 1961, the TRIDENT Office of BUSHIPS proposed that the U. S. Naval Research Laboratory undertake a study of corrosion in marine environments below the fouling line down to great depths. Extensive data are available on the corrosion of many structural materials near the surface, but there are several reasons one could not assume with confidence that corrosion at great depths would closely resemble that near the surface. At the surface most metals tend to accumulate attachments of barnacles (or other shellfish), gelatinous organisms, or various plants, all of which are largely missing at depth. In addition, the surface zone is partially irradiated by sunlight, which has been reported to accelerate corrosion, and the average temperature at the sites where most of the systematic gathering of marine corrosion has been done - Harbor Island, N. C., and Fort Amador, Panama - is higher than at depths. (The latter temperature approaches 0°C even in tropical waters.) Finally, where reaction products include some which are not condensed phases, such as hydrogen, pressure might possibly affect reaction kinetics.

The experiment reported herein, was designed from the following considerations:

(1) Knowledgeable designers of TRIDENT "hardware" will specify structural materials, coatings, and cathodic protection systems that have given satisfactory performance in surface applications and a quick verification of the general correctness of the implied assumption is desired.

(2) Much of the marine corrosion engineering is unwritten lore, and it would perhaps serve a useful purpose to have "horrible examples" of the sorts of unsatisfactory performance of metals which might be specified by, let us say, a competent electronic or aircraft engineering team unfamiliar with this lore.

(3) Minor changes in the chemical composition of zinc galvanic anodes can change their performance from perfectly satisfactory to entirely worthless. It was desired to verify that the not-so-minor change in environment from the generally warmer and biologically rich surface to the colder and almost sterile depths would not adversely affect the performance of our most reliable and efficient galvanic anodes.

(4) Equipment to be utilized in these experiments should be simple, easy to launch from a ship, able to survive the elements for the selected exposure periods, and easily retrieved.

From these considerations, 114 samples of metals and non-metals were selected and assembled on a vehicle and immersed in 5700 feet of water in the Tongue of the Ocean (TOTO) at Latitude 24° - 55.0'N and Longitude 77° - 48.2'W.

EXPERIMENTAL CONDITIONS

Table I gives representative data for water temperature, salinity, and oxygen content as determined by the U. S. Navy Oceanographic Office at a site nearby at the commencement of the exposure.

A schematic diagram of the test array is shown in Fig. 1. This scheme is believed to combine ease of shipboard handling with high reliability of retrieval and desirable experiment attitude. Its reliability is probably limited by the vulnerability of the plastic rope to fish or other source of damage, and future NRL experiments are being designed with steel wire rope. Photographs of the various racks are shown in Figs. 2-5. Details of construction are presented in NRL Memorandum Report 1282 (1).

MATERIALS

The materials exposed in this investigation are listed in Table II. These were all on the main rack at 5700 feet depth. In addition, several steel panels, some cathodically protected with zinc and aluminum anodes, and type 410 stainless steel with "built-in" crevices were exposed on the small racks located at both the surface and on the ocean bottom. These are listed in Table II. Although it would have seemed more desirable to obtain information on each of the materials at the surface, directly above the ocean bottom, and on the ocean bottom, so that direct comparison could be made between exposure conditions at these three locations, the necessary economy in weight dictated that only a few of the basic materials be exposed at the three locations.

Each of the metallic materials was exposed in duplicate. Nominally, the samples were 6 in. x 12 in. x 1/16 in. thick. The plastic and non-metallic samples were of varying thickness and 12 in. square. Additionally, a number of cathodically protected steel panels were included. The anodes were 6 in. x 1-1/2 in. and either 1/2 in. or 1-in. thick. They were bolted

to the steel panel through a one-inch thick phenolic spacer. A number of stainless steel panels with "built-in" crevices were included to obtain information on the crevice corrosion of these materials at great depth. These crevices consisted of drilled holes at each end of the panels through which was fitted a nylon bolt and nut. Rubber grommets were fitted into the drilled holes at one end of the panel; at the other end of the panel, nylon washers were fitted to each side of the hole.

All metal panels were secured to the aluminum cross-pieces of the specimen vehicle with two nylon bolts, with a thin strip of phenolic insulating the panels electrically from the aluminum frame.

Numerous samples of plastics, wood, and rubber were included in the test. These were furnished BUSHIPS by various shipyard materials laboratories.

PROCEDURES

All metallic samples were cleaned, weighed, measured, and packaged and shipped to the USS SAN PABLO at Philadelphia, the ship originally scheduled to accomplish the work. During ensuing ship schedule changes, all of the equipment was transferred to the USS SHELDRAKE in Nassau and on 4 April 1962 the installation of the array was completed from this ship. Details of this operation are presented in NRL Technical Memorandum 6320-16 (2).

On 25 July 1962, after 111 days exposure, the test array was retrieved by the Marine Acoustical Services research vessel G. W. PIERCE as part of their contract with the U. S. Naval Underwater Ordnance Station.

The surface spar buoy was hauled aboard, followed by the chain and surface exposure rack. The polypropylene rope was then wound on the power winch head and hauling of its 6000-feet length begun. A tensiometer was attached to the hauling pulley and at no time during the operation did the load exceed 1200 pounds. After approximately 1-1/2 hours of hauling this line, the underwater buoyancy cell, the main exposure vehicle, chain, anchors, and bottom exposure rack were retrieved. Visual inspection and photographs were made of all samples prior to the removal of one each of the duplicate panels. It was thought advisable to remove one sample of each material regardless of its state of deterioration as evidence of its behavior in the deep sea environment for nearly a four-months period. All samples that were removed were sealed in plastic bags and returned to NRL for study and evaluation.

OBSERVATIONS AND RESULTS

(a) Condition of the Test Equipment:

During the retrieval operations each component of the array was thoroughly examined for corrosion damage and marine fouling. The results of these examinations are presented in Table IV.

From this tabulation, it is obvious that all metallic components of the array were in excellent condition. It is to be noted that the aluminum anodes (5% zinc) attached to the underwater buoyancy cell did an excellant job of protecting all visible areas of the cell; it appeared to be in the same "as-new" condition as when lowered almost four months earlier. All of the vinyl protective coatings on the racks and buoyancy cell gave good protection to the aluminum except on the sharp edges of the angles and bars where the coating had originally been very thin.

(b) Condition of the Metal Test Panels:

Upon removal of the exposure racks from the water, the test panels were photographed and inspected. Since it was intended to evaluate the organically coated panels qualitatively only, none of these were removed from exposure unless they had deteriorated beyond the point where adequate protection was rendered the steel.

Upon being returned to NRL, the metallic samples were appropriately chemically cleaned, weighed, measured, and evaluated for the extent of corrosion. The plastic and other non-metallic materials were weighed and returned to the respective Naval laboratories which furnished them originally.

Comparative corrosion data for the metallic materials exposed at three depths are presented in Table III. Table V lists the corrosion data for all the metals exposed on the main rack at 5700 feet. A summary of the results contained in these two tables follows:

(1) Scatter of results on specimens exposed directly on the bottom confirmed that the calcareous ooze is protective against corrosion. (It was in anticipation of this that the main experiment was buoyed well off the bottom.)

(2) Cathodic protection by conventional galvanic anodes was again very effective on bare steel at depth (5700 feet), but the deterioration of both aluminum and zinc anodes was slightly greater at 5700 feet than at the surface (Fig. 6).

(3) Both general corrosion and pitting of low carbon steel was more severe at the surface than at depth (Fig. 7).

(4) Copper, 90-10 cupro-nickel, Naval brass, and phosphor bronze suffered slight overall superficial corrosion when exposed at depth.

(5) HY-80 steel suffered both severe overall corrosion and pitting at depth, probably typical of low-alloy steel.

(6) Zinc and two samples of galvanized steel suffered overall superficial attack at depth.

(7) Proprietary alloy I*, proprietary alloy M**, type 304 stainless, and type 316 stainless suffered no overall attack but were slightly corroded at crevices formed by the nylon bolts and washers and the phenolic backing strip.

(8) Proprietary alloy T***, type 410 and type 430 stainless were corroded locally and had suffered perforation of the sheet when exposed at depth. Type 410 suffered much more severe crevice corrosion when exposed at depth as compared with the surface (Fig. 8).

(9) Type 1100 aluminum sheet was perforated and suffered severe crevice corrosion at depth. Both type 6061 and type 7079 sheet suffered slight overall corrosion and crevice corrosion. Type 5086 sheet showed no evidence of general or crevice corrosion.

(10) Only two materials in these tests (other than those under cathodic protection or protected by a satisfactory paint system) showed complete absence of corrosion - titanium and type 5086 aluminum.

Two foot lengths of five samples of wire rope were exposed. The following materials were represented:

(1) Electro-galvanized steel - heavily coated with protective compounds.

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* Proprietary alloy I - 11-15% Cr - 79% Ni
** Proprietary alloy M - 70% Nickel - 30% Copper
*** Proprietary alloy T - 17% Cr - 14 1/2% Mn - 1% Si

(2) Mild plow steel - heavily coated with protective compounds.

(3) Aluminum-coated steel - no oil or coating.

(4) Proprietary alloy T - oiled.

(5) Type 304 stainless steel - oiled.

The oil or protective coatings completely protected the wire rope of electro-galvanized steel, mild plow steel, and type 304 stainless from corrosion. The aluminum-coated steel contained a large amount of white aluminum salts with no rusting of the base steel in evidence. The proprietary alloy T rope was corroded locally and showed considerable rust. Some of the individual wires of the strand had suffered breakage from corrosion.

(c) Condition of the Non-metallic Materials:

Table VI lists the changes in weight after exposure and return to NRL of various non-metallic materials included in these tests.

The following materials had a relatively low water absorption after exposure to depth:

Syntactic foam (micro balloons).
Glass reinforced plastic - filament wound epoxy laminate.
Glass reinforced plastic - polyester laminate.
Compressed wood - resin treated.

The following materials showed an intermediate water absorption:

Urethane foam - high density (45 lbs/cu ft).
Angelique (wood).
Teak (wood).

Both balsa and Alaska yellow cedar showed a very high extent of water absorption.

No measurements were obtained on neoprene, rubber sheet, rubber O-rings, and nylon or dacron rope though each of these materials appeared in good condition following their retrieval from exposure.

(d) Condition of Painted Panels:

A summary of the qualitative evaluation of all organic protective coatings included in these tests is given

in Table VII. This indicates that selected organic coatings, properly applied, afforded excellent protection to steel submerged to depth for the time period involved. Possibly, the deterioration at the scribe for each system exposed is more severe than would have been found if they had been exposed at the surface.

It is to be noted that no marine fouling was found on any of the panels exposed at the 5700 foot depth. This probably obviates the necessity of using anti-fouling top coats in any coating system proposed for future exposure at depth. The absence of marine fouling may also explain the good protection observed by these coatings exposed at depth since profuse fouling at the surface is often responsible for premature failure of these coatings.

DISCUSSION

In these exposure tests, low carbon steel suffered greater general corrosion and pitting at the surface than it did at 5700 feet. This is illustrated in Fig. 6 which compares the appearance of these panels.

Cathodic protection of steel with commercial zone and aluminum anodes was complete at both the surface and depth. Samples exposed at the surface fouled about the same as was observed on unprotected steel. The anodes appeared to deteriorate at a slightly greater rate at depth than at the surface. However, this fact is inconclusive because of the small number of panels exposed, but if the effect is real it may be a reflection of the "screening" effect of the fouling.

All materials included in these tests with the exception of type 5086 aluminum and titanium suffered corrosion of varying degrees. Most of the materials appeared to be much more prone to crevice corrosion at depth, particularly the type 400 series of stainless steels. From the standpoint of practical corrosion engineering, however, nothing has been seen to lead one to select materials or protective schemes for deep submergence other than those which have been successful in shallow immersion, except that antifouling precautions may be relaxed at sufficient depths.

SUMMARY AND CONCLUSIONS

1. This paper gives the results of the exposure of various materials at several depths up to 5700 feet in the Tongue of the Ocean for a period of approximately 3-1/2 months (111 days).

2. The engineering approach utilized in designing these exposure buoy systems is believed essentially sound, but subsequent casualties to additional experiments would indicate the desirability of modification of certain details, including replacement of plastic rope with wire rope.

3. Low carbon steel suffered much greater general corrosion and pitting when exposed at the surface than it did at 5700 feet; the pattern of corrosion for this material was different at the two locations. All materials included in these tests with the exception of type 5086 aluminum and titanium suffered corrosion of varying degrees, except those cathodically protected or having suitable paint systems. Most of the materials appeared to suffer more extensive crevice corrosion at depth, particularly the type 400 series of stainless steel.

5. Organic coatings appeared to afford excellent protection to steel surfaces submerged to 5700 feet in the ocean for the specified exposure period.

6. The only effect observed on the deep submergence of non-metallic materials was that most of the woods and porous plastics absorbed considerable amounts of water with resultant damage.

ACKNOWLEDGEMENTS

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REFERENCES

1. NRL Memorandum Report 1282, March 1962.
2. NRL Technical Memorandum 6320-16, April 1962.
3. NRL Memorandum Report 1242, November 1961.

TABLE I

HYDROGRAPHIC ASPECTS TOTO WATERS
MADE BY THE U. S. NAVAL OCEANOGRAPHIC OFFICE
MARCH 1962

DEPTH FEET	TEMP °C	SALINITY 0/00	O_2 ml/L
Surface	24.08	36.79	4.59
33	-	36.73	4.58
66	24.09	36.72	4.61
164	24.14	36.73	4.26
249	24.13	36.78	4.42
331	24.14	36.79	4.42
495	23.92	36.74	4.15
663	22.35	36.70	4.15
820	19.27	36.56	4.13
1158	17.31	36.36	3.92
1654	13.78	35.82	3.46
1985	11.73	35.55	3.19
2316	10.03	35.33	3.11
2648	8.09	-	3.59
3310	-	35.04	4.96
4967	4.18	35.00	5.73

TABLE II

LIST OF METALS EXPOSED

Low carbon steel (AISI 1010)
Steel, HY-80
Stainless steel, type 304
Stainless steel, type 316
Stainless steel, type 316, with built-in crevice
Stainless steel, type 410, with built-in crevice
Stainless steel, type 410
Stainless steel, type 430
Stainless steel, Proprietary Alloy T
Titanium
Galvanized steel
Zinc
Proprietary Alloy M
Copper-nickel, 90-10
Naval brass
Phosphor bronze
Aluminum - 1100
Aluminum - 5086
Aluminum - 6061
Aluminum - 7079
Proprietary Alloy I
Copper
Hastalloy, N - cladding sections
Wire rope - zinc coated
Wire rope - aluminum coated
Wire rope - Proprietary Alloy T coated
Wire rope - stainless, type 304

PLASTICS AND RUBBER

Glass Reinforced Plastic - Filament Wound Epoxy Laminate
Glass Reinforced Plastic Polyester Laminate
Urethane Foam - High Density (45 lb/cu. ft.)
Syntactic Foam (Microballoons)
Neoprene, ML-C-589
Neoprene, ML-C-619
Rubber Sheet, MIL-R-15058, Type 3, Class 1
Rubber Sheet O-Rings, MIL-P-5516, Class B

WOODS AND FIBER

Dicorynea paraensis, Angelique
Ochroma lagopus, Balsa
Chamaecyparis nootkatensis, Alaska Yellow Cedar
Tectoua granois, Teak

(continued)

TABLE II (continued)

Compressed Wood, resin treated
Nylon Rope, twisted
Nylon Rope, braided
Dacron Rope, twisted

ORGANIC COATINGS (OVER MILD STEEL)

SYSTEM I - VINYL - MIL-P-15934:

Mark B-1		
Wash Primer,	MIL-P-15328B	0.5 mil.
	MIL-P-15930	1.0 mil.
(non toxic)	MIL-P-15934	3.2 mil. 3 coats
		4.7

SYSTEM II - VINYL ANTIFOULING - MIL-P-15931, FORMULA 121:

Wash Primer		0.7 mil.
Mark A-1	MIL-P-15930	1.2 mil.
Rosin Cu oxide (antifouling)	MIL-P-15931	3.3 mil. 3 coats
		5.2

SYSTEM III - DOLFINITE - X-1265 - ANTIFOULING:

Wash Primer		0.5 mil.
Mark A-3,	MIL-P-15930	1.3 mil.
(Antifouling)	(Dolfinite - X-1265)	3.2 mil. 3 coats
		5.0

SYSTEM IV - ACRYLIC - M-559:

Wash Primer		0.6 mil.
Mark A-5,	MIL-P-6889	1.1 mil.
Acrylic A/F Paint, M-559		3.2 mil. 2 coats
		4.9

SYSTEM V - URETHANE:

Wash Primer	0.7 mil.
Mark C-1, Urethane system	
Ratio 4/1, National Lead No.	3.5 mil. 2 coats
	4.2

SYSTEM VI - EPOXY, DEVRAN:

Mark D-1 (Devran)	3.3 mil. 3 coats
Ratio 19/1 MD-2500 - Prop. System	
	3.3

TABLE III

COMPARATIVE DATA FOR METALS EXPOSED AT THREE DEPTHS

MATERIAL	SURFACE (50' DEPTH)			5700' DEPTH			BOTTOM (5750' DEPTH)		
	Wgt Loss Gms	Deepest Pit Mils	Avg 5 Deepest Pits	Wgt Loss Gms	Deepest Pit Mils	Avg 5 Deepest Pits	Wgt Loss Gms	Deepest Pit Mils	Avg 5 Deepest Pits
(1) Low Carbon Steel, AISI 1010	57 *	19	8.2	20 *	3	2.3	12 *	2	1.5
(2) Low Carbon Steel, AISI 1010 one side protected with chromate primer and vinyl tape	32 **	12	9.6	10 **	4	3	10 **	3	2
(3) Low Carbon Steel, AISI 1010 with 5% zinc aluminum anode	0	0	0	1	0	0	1	0	0
(4) Low Carbon Steel, AISI 1010 5% zinc aluminum anode, one side protected with chromate primer and vinyl tape	0	0	0	1	0	0	0	0	0
(5) Low Carbon Steel, AISI 1010 with zinc anode, one side protected with chromate primer and vinyl tape	0	0	0	1	0	0	0	0	0
Stainless Steel, Type 410 (with built-in crevices)	0	0	0	7	63 Perforated	63	-	-	-
Aluminum anode from (3)	14	-	-	33	-	-	2	-	-
Aluminum anode from (4)	12	-	-	13	-	-	3	-	-
Zinc anode from (5)	22	-	-	37	-	-	12	-	-

* 1 gram = 120 milligrams per square decimeter
** 1 gram - 215 milligrams per square decimeter

TABLE IV

SUMMARY OF CONDITION OF UNDERWATER PARTS

COMPONENT	DEPTH	MATERIAL	CORROSION	FOULING
(1) Spar buoy	Surface	Fiberglass reinforced plastic with Stainless 304 fittings.	None - Underwater fittings of Stainless Steel, Type 304 protected with Low Carbon Steel Anodes.	Coverage - 10% Goose Barnacles, Erect, Bryozoa, Hydroids, Green Algae - on fittings only as buoy was painted with vinyl antifouling paint.
(2) 1/2" Chain	0' to 50'	Galvanized Steel	Very Slight corrosion of zinc coating.	None
(3) Surface Rack	50'	Aluminum 6061-T6 vinyl coated.	Slight - Some corrosion of edges where coating was thin. Coating in excellent condition. Some crevice corrosion at Aluminum fastener.	Coverage - 80% Goose Barnacles - 5% Hydroids, Erect Bryozoa - 80% Green Algae - 1% Mollusks - 1%
(4) Suspension Rope	0' to 5650'	Black polypropylene	----	Coverage - 80% at surface to fraction of a percent below 300 feet. 0' to 45' - Green Algae - 1% Hydroids and Erect Bryozoa - 80% Mollusks - <1% Goose Barnacles - 1% 0' to 1000' - Hydroids - Erect Bryozoa - <1% Goose Barnacles - <1% 900' to 5600' - Scyphozoa (Jelly Fish Type) - <0.1%
(5) Underwater Buoyancy Cell	5650'	Aluminum 6061-T6 One coat vinyl Zinc Chromate primer.	None - Buoyancy cell completely protected with Aluminum anodes 5% Zinc alloy. Zinc Chromate primer in excellent condition	None

(continued)

TABLE IV (continued)

COMPONENT	DEPTH	MATERIAL	CORROSION	FOULING
(6) Chain Slings and connector Link	5650'	Galvanized Steel	Very Slight - corrosion of Zinc coating.	None
(7) Main Exposure Vehicle and Center Rack	5700'	Aluminum 6061-T6 vinyl coated.	Slight - some corrosion of edges where coating was thin. Coating in excellent condition. Some crevice corrosion at Aluminum fasteners.	None
(8) 7/16" Rope, Safety Link	5700' to 5750'	Black polypropylene	----	None
(9) Anchors and Bottom Chain	5750'	Galvanized steel	Very Slight - corrosion of Zinc coating.	None - No visible marine life - anchors carried up several pounds of white calcareous ooze from the bottom.
(10) Bottom Rack	5750'	Aluminum 6061-T6 vinyl coated.	Slight - some corrosion of edges where coating was thin. Coating in excellent condition. Some crevice corrosion at Aluminum fasteners.	None - No visible marine life - slight amount of calcareous ooze from bottom adhering to rack.

TABLE V

SUMMARY OF RESULTS OBTAINED ON METALLIC SAMPLES AT 5700 FEET

MATERIAL	SURFACE APPEARANCE	LOSS IN GRAMS WT*	PITTING - MILS DEEPEST	PITTING - MILS AVG*	CREVICE CORROSION
1010 Steel	General surface rusting	19 20	3.0 3.0	2.2 2.3	Crevice attack around backing strip
1010 Steel with Al anode	No corrosion	1	0	0	None
1010 Steel with Zn anode	No corrosion	1	0	0	None
Titanium	No attack	0	0	0	None
Copper	Slight surface attack	12.4	0	0	None
Zinc	General surface attack	16	8	5	Very slight around washers
90 Cu - 10 Ni	General surface tarnish	6	0	0	None
Proprietary Alloy I	No attack	1	0	0	Crevice 10-15 mils deep attack at edge of backing strip
Naval Brass	General surface attack	8.9	0	0	None
Phosphor Bronze	Slight surface attack	3.3	0	0	None
HY-80	Severe general surface attack	25.7	10	8	Slight around backing strip
Galvanized steel 2 oz coating	General surface attack	12	0	0	None
Galvanized 3 oz continuous run	General surface attack	12	0	0	None
Al - 1100	Local pitting of surface	3	63	Sheet Perforated	Severe at washers and backing strip
Al - 6061	Slight surface attack and general pitting	1	20	12	Slight around washers and backing strip
Al - 7079	Slight surface attack exfoliation	1	16	11	Crevice corrosion at washers and backing strip

(continued)

TABLE V (continued)

MATERIAL	SURFACE APPEARANCE	LOSS IN GRAMS WT+	PITTING - MILS DEEPEST	PITTING - MILS AVG*	CREVICE CORROSION
Proprietary Alloy M	No attack	1	0	0	Slight crevice corrosion at backing strip
304 Stainless Steel	No attack	0	0	0	Slight crevice corrosion at one washer
316 Stainless Steel	No attack	0	0	0	Very slight under one washer
410 Stainless Steel	Very localized surface pitting	7	63 Perforated	63	Severe at washers and backing strip
Proprietary Alloy T	Localized surface pitting	7	63 Perforated	63	Severe at washers and backing strip
430 Stainless Steel	Localized surface pitting	8	132 Perforated	132	Severe at washers

*Average of 5 deepest pits.

+ 1 gram = 120 milligrams per square decimeter.

TABLE VI

CHANGES IN WEIGHT OF NON-METALLICS

MATERIAL	ORIG. WT	GAIN IN GRAMS	% GAIN IN WT.
Poly Ester Microballoon	4478	53	1.2
Urethane 45 lb/cu. ft.	6829	2008	29.4
GRP - 1000 Cloth	1404	5	0.4
Compressed Wood	9935	47	0.5
GRP - Filament Wound	1963	7	0.4
Angelique	8822	3030	34.3
Balsa (2 samples)	6612	5220	78.9
	5757	5011	87.0
Teak	8275	3685	44.5
Alaska Yellow Cedar	7819	4334	55.4

TABLE VII

QUALITATIVE EVALUATION OF ORGANIC PROTECTIVE COATINGS AT 5700 FEET DEPTH

COATING		Alligatoring	Blistering	Checking	Cracking	Flaking	Peeling	Rusting	Erosion	RATING
		Type of Failure-Rating*								
Dolfinite Y-1265, AF	Scribed	-	-	-	-	3	3	3	-	3
	Un-scribed	-	-	-	-	-	-	-	-	1
MIL-P-15931 AF-121	Scribed	-	-	-	-	3	3	3	-	3
	Un-scribed	-	-	-	-	2	-	-	-	2
Urethane	Scribed	-	-	-	-	2	2	3	-	3
	Un-scribed	-	-	-	-	-	-	-	-	1
Epoxy Devran	Scribed	-	-	-	-	-	2	3	-	3
	Un-scribed	-	-	-	-	-	-	-	-	1
MIL-P-15934 Vinyl	Scribed	-	-	-	-	2	-	3	-	3
	Un-scribed	-	2	-	-	-	-	-	-	2
M-559 Acrylic	Scribed	-	-	-	-	2	-	3	-	3
	Un-scribed	-	3	-	-	3	-	3	-	3
Chromate Primer Vinyl Tape	Un-scribed	-	2	-	-	-	-	1	-	2
Chromate Primer Vinyl Tape	Un-scribed surface 50 ft depth	-	-	-	-	-	3	3	-	3

*Description of Rating:

1. No deterioration.
2. Some deterioration but underlying metal surface still being protected. Coating considered SATISFACTORY. Do not remove from exposure.
3. Heavily deteriorated. Coating defects sufficient to allow corrosion of underlying metal surface. Coating considered UNSATISFACTORY. Remove from exposure.

NOTE: None of the panels exposed at 5700 feet exhibited any type of visible marine fouling.

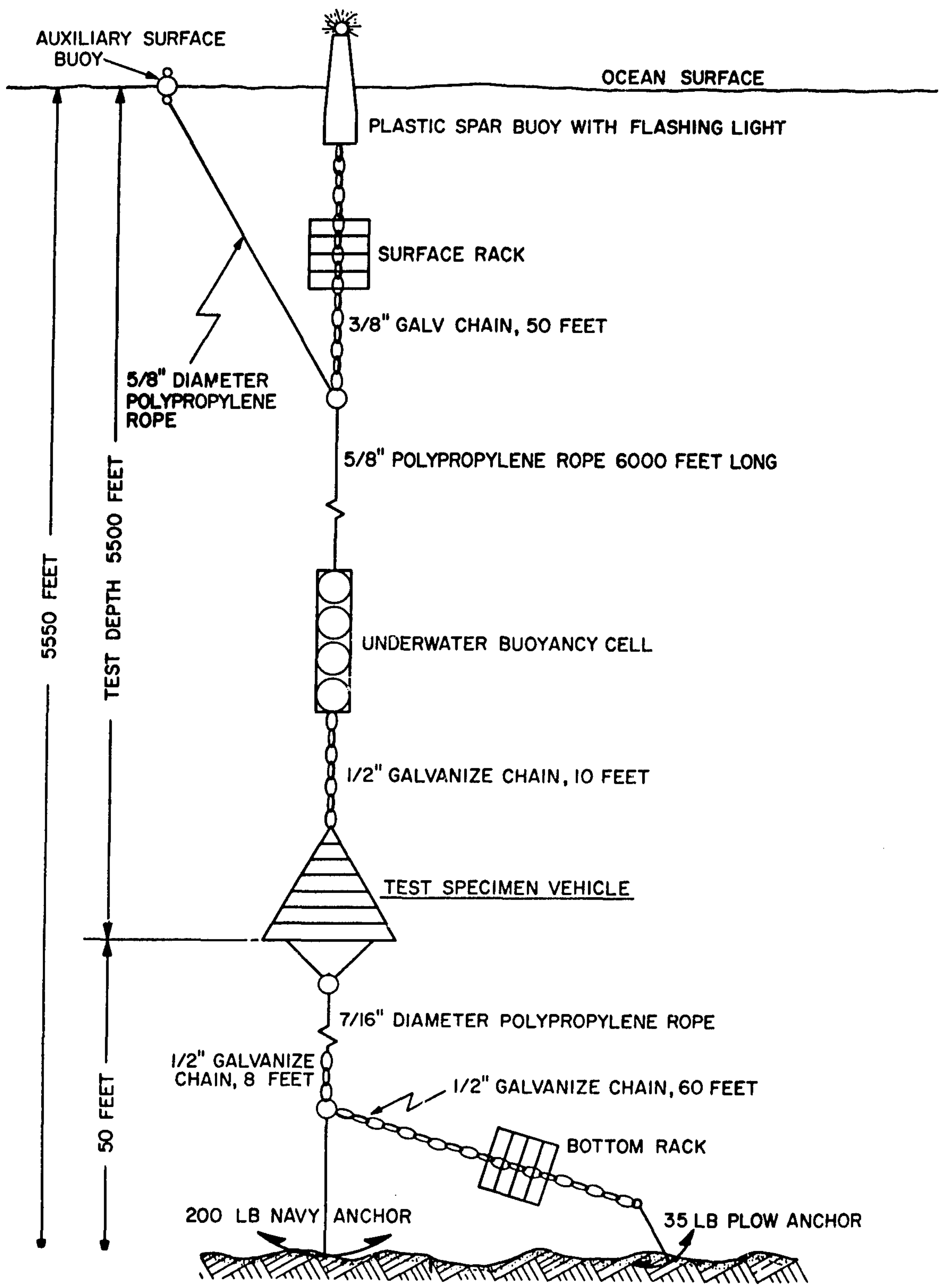

Fig. 1 - Schematic diagram of deep sea corrosion test array

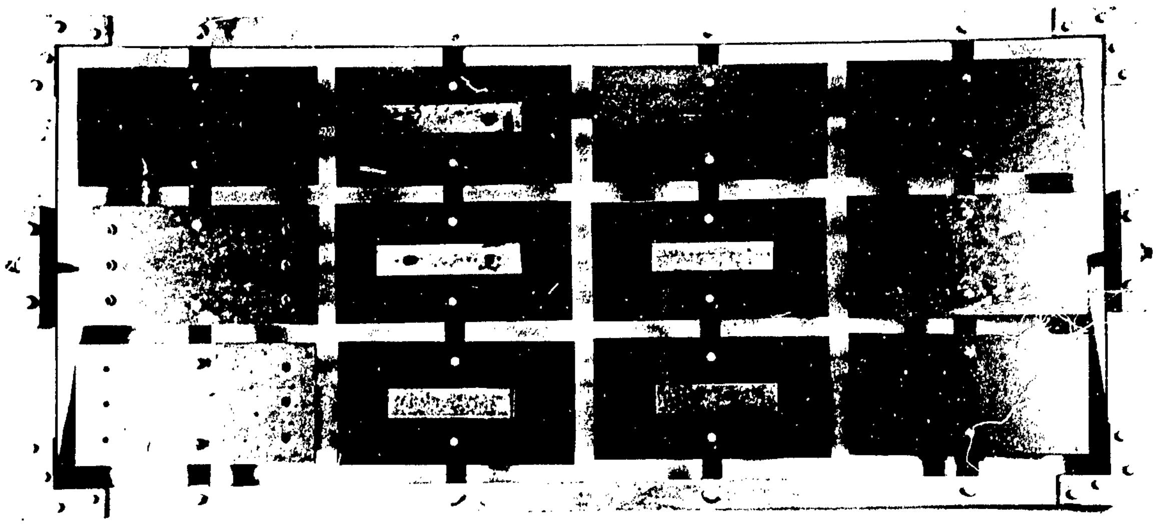

Fig. 2 - Surface exposure rack

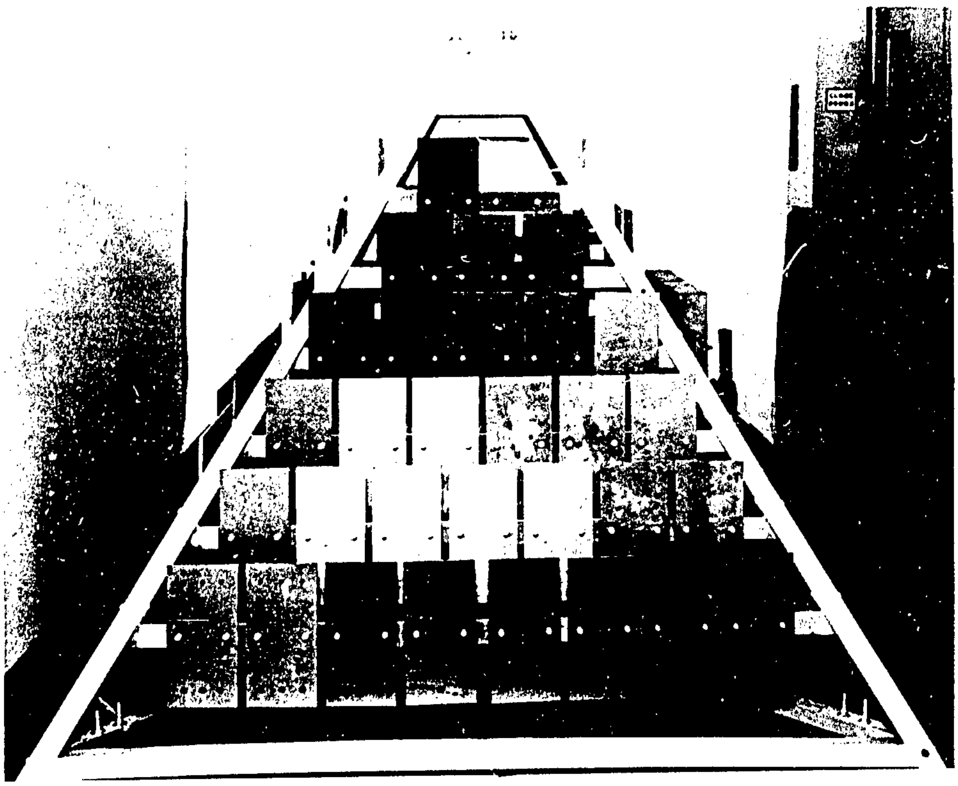

Fig. 3 - Main exposure rack of corrosion test array

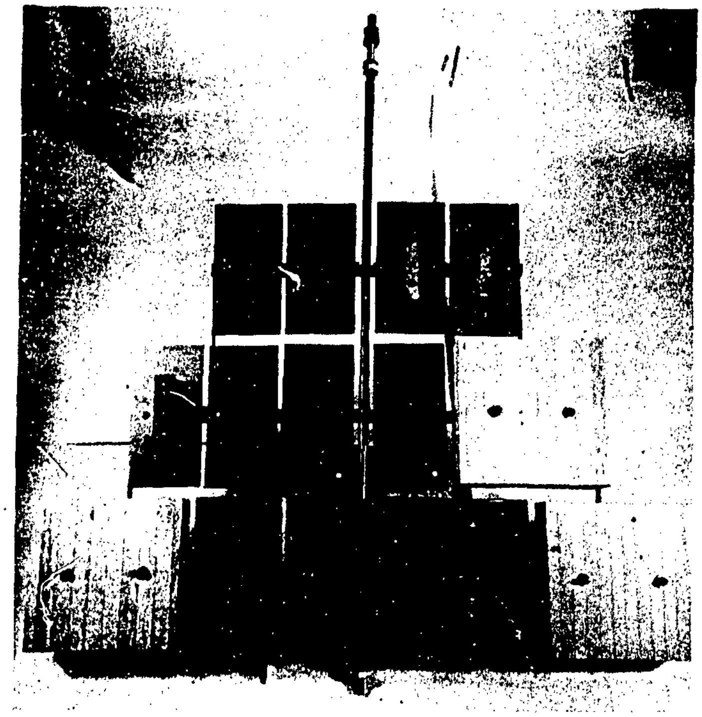

Fig. 4 - Center rack of main exposure array

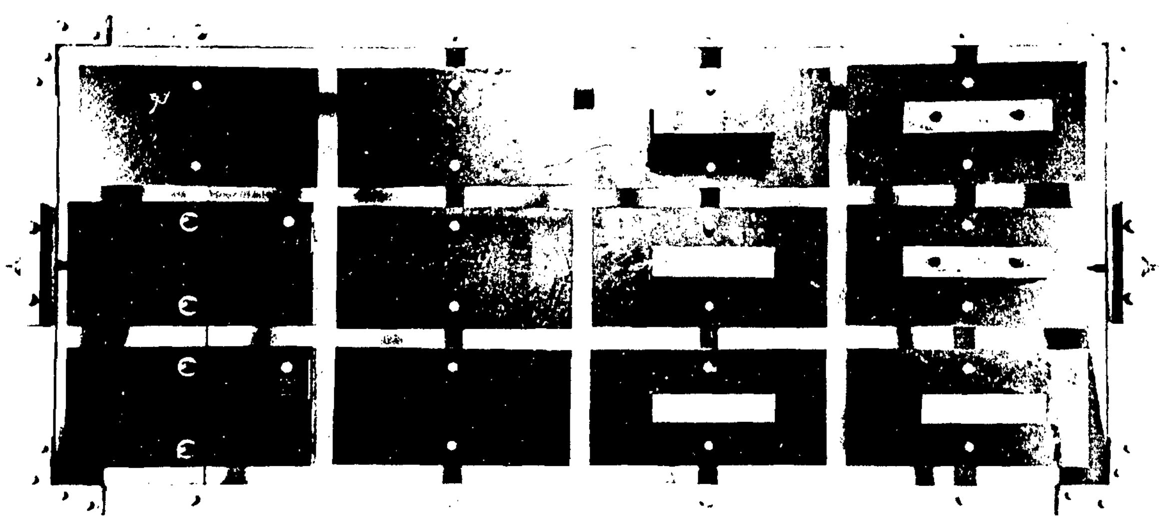

Fig. 5 - Bottom exposure rack

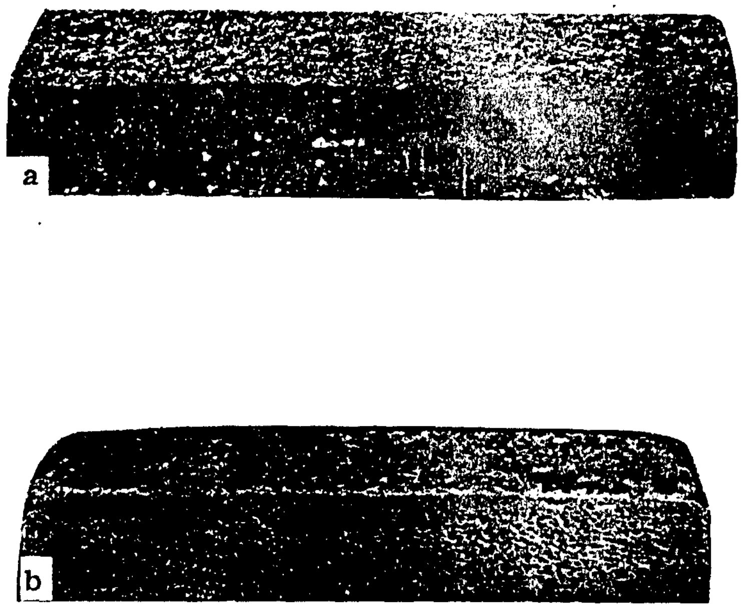

Fig. 6 - Comparison of aluminum anodes used to protect low carbon steel at (a) the surface, and (b) at 5700 feet

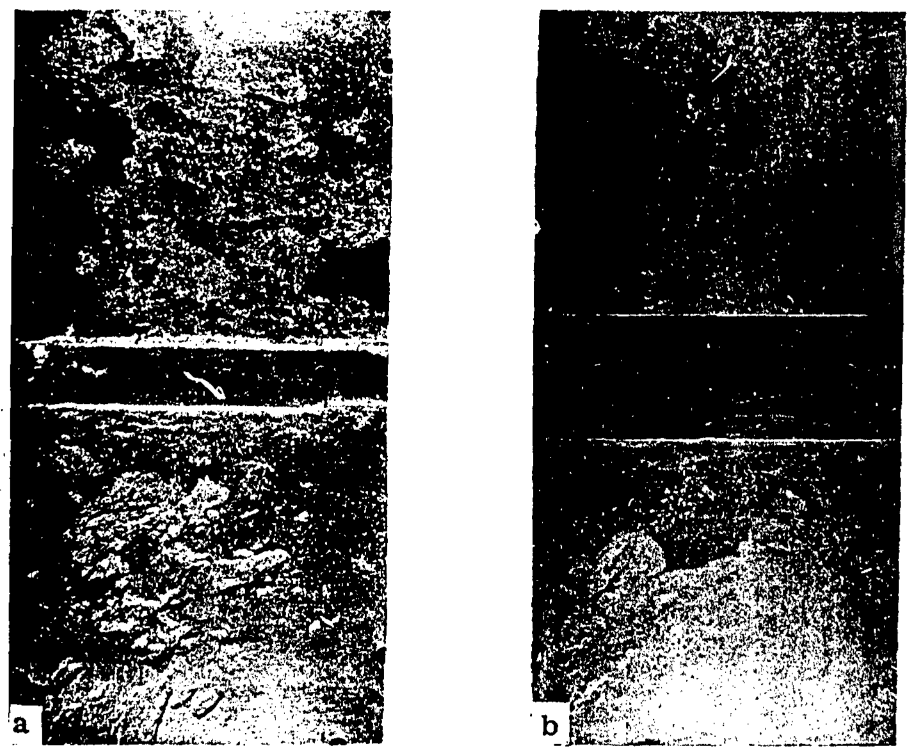

Fig. 7 - Comparison in corrosion of low carbon steel (a) at the surface, and (b) at 5700 feet

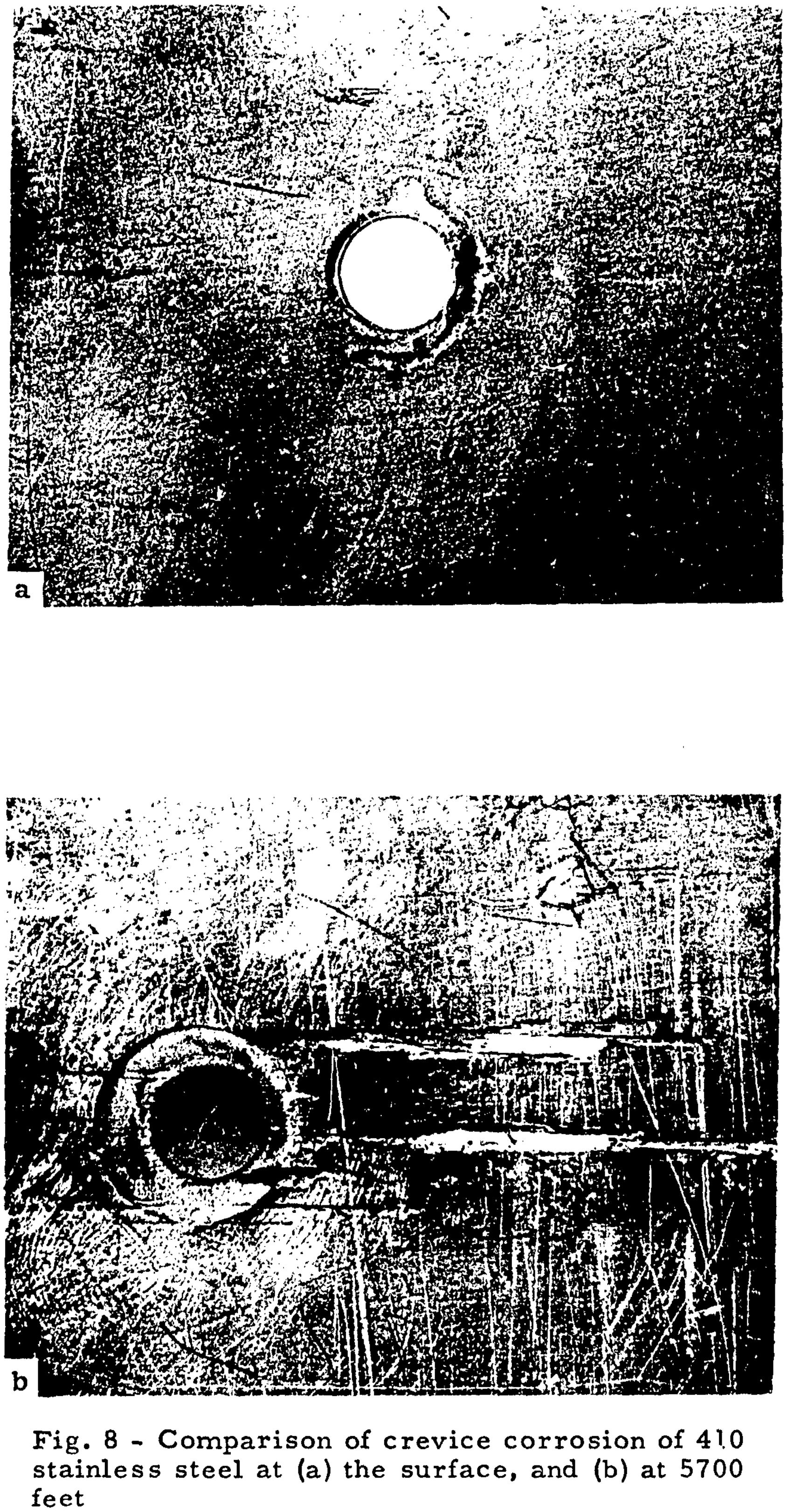

Fig. 8 - Comparison of crevice corrosion of 410 stainless steel at (a) the surface, and (b) at 5700 feet